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Complexity-aware principles for agri-food system interventions: Lessons from project encounters with complexity

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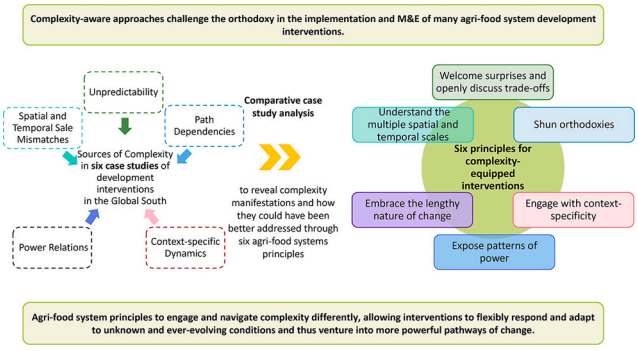
HIGHLIGHTS

- Complexity is a core feature of agri-food systems, but it is unclear how to tackle it in development interventions.
- Comparative case study analysis to reveal multiple manifestations of complexity.
- Six complexity-aware principles identified to show how complexity could be better navigated.
- Principles to make development interventions equipped towards uncertain and ever-evolving agri-food system contexts.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Complexity has long been recognised as a key feature of agri-food systems. Yet, it remains largely theoretical or poorly addressed in practice, hampering the potential of international development projects to address agriculture and food-related challenges in the Global South.
OBJECTIVE: The paper identifies and examines six sources of complexity that can manifest in projects, namely: unpredictability; path dependencies; context-specific dynamics; power relations; multiple temporal and spatial scales. It then proposes and tests six agri-food system principles that could be drawn upon to more successfully navigate this complexity. The aim of the paper is to illustrate how these principles could help projects respond to the changing circumstances and unpredictable turns of agri-food systems contexts in a different way, which flexibly embraces complexity. This flexibility is essential in an age of uncertainty and transformation.
METHODS: Comparative case study analysis of six projects implemented by the CGIAR: aflatoxin control in groundnuts in Malawi (1), pigeonpea in Eastern and Southern Africa (2), sorghum beer in Kenya (3), sweet sorghum for biofuel in India (4), precooked beans in Uganda and Kenya (5), Smart Foods in India and Eastern Africa (6). The projects aimed to either increasing smallholder farmers' incomes or addressing food and nutrition security, or both. They were specifically selected as all they were affected by some of the sources of complexity,

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which hampered the projects to different extents. This makes the cases relevant for not only illustrating manifestations of complexity, but also help reflect on alternative strategies to tackle it.
RESULTS AND CONCLUSION: The analysis of the case studies reveals how complexity can frustrate objectives of development interventions under several aspects. It also serves to discuss how complexity can be more successfully navigated (within but also beyond the selected cases) by applying the set of proposed agri-food system principles. The principles are also presented as ways future interventions could avoid clinging to what is "known to work" and instead venture into more powerful pathways of change.
SIGNIFICANCE: The following complexity-aware principle are proposed: Welcome surprises and openly discuss trade-offs; Shun orthodoxies; Engage with context-specificity; Expose patterns of power; Embrace the lengthy nature of change; Understand the multi-scale (in terms of space and time) nature of agri-food systems contexts. These principles could be used by project designers and implementors to cope with the complexity and uncertainty that will inevitably be encountered in agri-food system interventions, and can no longer be ignored.

"*Malum consilium quod mutari non potest.*"-
"Bad is the plan that cannot change."
Publius syrius (85 – 43 BC)

1. Introduction

The global development agenda is increasingly concerned with issues at the nexus of food, environment and human well-being that are characterised by systems complexity (hereafter complexity) (Dekeyser et al., 2020; Hebinck et al., 2021). Complexity here refers to the interconnectedness of different system components; the way in which the behaviour and outcomes of the system cannot be understood by examining the individual components; and the evolutionary dynamics that emerge from the interaction of different components and the responses of these different components to external shocks and drivers (Emery, 1970; Hall and Clark, 2010; Ramalingam et al., 2008; Sanders, 1998). The lack of understanding -and even engagement – with complexity in a system sense has, however, created many unintended consequences for food security, health and the environment (Barnhill and Fanzo, 2021). The unpredictable dynamics of the complex systems make food systems vulnerable to unexpected cause and effect relationships and trade-offs (Mausch et al., 2020).

To mention a few examples, the modernisation of agriculture allowed enormous and welcome advances in agricultural and food production since the late 1950s. Yet, it also contributed to climate change, that now puts production at risk (IPES, 2015). This illustrates complex system behaviour, as the improvements in one area (agricultural and food production) led to adverse effects in another (climate change), demonstrating the interconnectedness and unintended consequences within the system. Increased prosperity and industrialisation have led to overconsumption and obesity in some countries, showing how economic growth can have unexpected and non-linear outcomes within and beyond the food system (e.g. in terms of affecting population health) (De Schutter, 2014; Rivera-Ferre, 2009). The global COVID-19 pandemic and the recent Ukraine conflict have disrupted global food supply changes in unexpected ways, underscoring interdependencies between sectors and suggesting the high dependence of agri-food system on socio-political dynamics (Slavchevska et al., 2022; Word Bank, 2022).

The recognition of complexity in relation to food and agriculture related development challenges in the Global South is nothing new (Douthwaite and Hoffecker, 2017; Pimentel, 1966). Since at least the 1960s, international development assistance has grappled with various manifestations of complexity. For instance, it is widely recognised that interventions tackling malnutrition and food insecurity, underpinned by efforts to increase kilocalories intake, performed below expectations (Hadjikakou et al., 2017; Mausch et al., 2020). The systemic nature of these challenges would instead require much deeper consideration of the forces and dynamics that determine food and nutritional security outcomes (Conti et al., 2021b; Hambloch et al., 2022; Kok et al., 2023). Rather than simply increasing yields, concerted actions were required across social, economic and political domains to address the root causes of these challenges (Conti et al., 2021b; Liang, 2019; Sen, 1981).

Over the years, significant efforts have been made to understand and engage with the complexity of agricultural and food challenges by applying a complex adaptive system perspective and related framings (Hall and Clark, 2010; Kampelmann et al., 2018). For instance, from the 1970s onwards, research organisations such as the CGIAR adopted a farming system framing for agronomy research (Collinson, 2000; Greenland, 1997; Pingali, 2001). Later, new framings emerged, such as the food system framing or the agri-food system framing. These framings were aimed at capturing the totality of processes, actors, interaction and scales in the agriculture and food space (Ericksen, 2008; Thompson et al., 2007). They started being increasingly used in relation to the growing concerns over sustainability issues (as in the case of participatory action research in many of the CGIAR programs) (Leeuwis et al., 2017; Wani, 2012). To date, they are still a critical point of discussion for research organisations trying to align and respond to the sustainability transformation agenda (CGIAR, 2020; Conti et al., 2024a; Schut et al., 2024). The transformation agenda suggests that structural and concomitant changes in *all* elements of the agri-food system (e.g. technologies, patterns of practice, cultures and behaviours, infrastructure, policies and power dynamics) are needed to shift the direction of these systems from unsustainable patterns to long-term environmental viability, social justice and inclusion, and equity (Conti et al., 2021b; Rockstrom et al., 2023).

However, despite the rhetoric and wide use of the terms food or agri-food systems in recent debates and mission statements (CGIAR, 2020; FAO, 2018), as well as practical attempts to incorporate complexity thinking into research and development (Orr et al., 2018; Ramalingam, 2015), complexity remains poorly understood and has yet to inform the emergence of a distinctive body of development practice (Cholez et al., 2023; Douthwaite and Hoffecker, 2017). Challenging the "orthodoxy in much of mainstream research and evaluation practice" (Mayne et al., 2017), complexity-aware approaches remain poorly implemented in interventions (Foran et al., 2014; Hambloch et al., 2022).

The purpose of this paper is to contribute to developing practical principles that can guide the implementation of complexity-aware approaches in agricultural research for development interventions. Complexity-aware approaches can be broadly defined as ones that are ready to continuously explore system dynamics, accommodate novelty, re-examining assumptions, and generally have an open, rather than a pre-defined, agenda (Douthwaite and Hoffecker, 2017; Hertz et al., 2021). Specifically, we will investigate interventions that have various food and nutrition security and improved farm income impact aspirations. What is common in these interventions is that their scope, by necessity, spans the production and consumption domain of the food system and, therefore, the broader social, economic, and political context in which these domains are embedded. To achieve this, the paper draws from complexity and agri-food system perspectives to identify six sources of complexity that interventions are going to need to navigate in their encounters with complexity: unpredictability; path

dependencies; context-specific dynamics; power relations; temporal and spatial scale mismatches. These sources are then used to interpret the experiences of six case studies of interventions that have all encountered different aspects of complexity. The complexity and agri-food system perspective are used to frame a discussion on the different ways the interventions described in the case studies could have better navigated the contingencies and consequences of complexity encountered. Finally, the paper highlights the way complexity-aware principles that emerge from agri-food system perspective could be used by help project designers and implementors to cope with the uncertainties and complexity encountered in project settings.

The paper begins by exploring the concept of complexity in agri-food systems and the principles that emerge from recent thinking. These principles then form the main analytical lens for to interpret the experiences outlined in the case studies and the subsequent discussion of these.

2. Complexity in Agri-food systems

Thompson and Scoones (2009) coined the idea of agri-food systems as a way of drawing attention to the evolving dynamics of agricultural and food systems. Agri-food systems not only encompass all processes involved in growing, processing, distributing, consuming, and disposing of foods, but also the broad network of actors (and their often contrasting or conflicting interests and values) and the multiple ecological, social, economic, political interactions and institutional frameworks that shape these systems and operate at various scales (Blake et al., 2019; Hall and Dijkman, 2019; IPES, 2015). It is the multiplicity of processes, actors, and interactions, coupled with the unpredictable events that emerge from these dynamics, that cause agri-food systems to exhibit features of systems complexity. These include non-linearity of cause-and-effect relationships, unexpected behaviours and feedback loops, and multi-scale (in terms of space and time) processes (Dekeyser et al., 2020; Reichelt and Nettle, 2023). The presence of historical and concealed path dependencies equally shape agri-food systems development in unanticipated and intangible ways (Conti et al., 2021b; van Bers et al., 2019).By reviewing the literature on agri-food systems, six sources of complexity can be identified:

2.1. Unpredictability (1)

The presence of “unknown unknowns” (Snowden and Boone, 2007) might lead to outcomes that are different from what initially envisioned (Thompson and Scoones, 2009). Unpredictability manifests as i) unexpected *events* happening in agri-food systems (e.g. sudden shocks such as natural hazards); ii) unexpected outcomes of interactions between actors and, more generally, between the multiple social, economic and environmental components (Ericksen, 2008; Holling and Meffe, 1996); iii) unexpected trade-offs, where trade-offs are defined as conditions or actions that, if positively affecting one intervention target might negatively affect another, predictably or less so (Mausch et al., 2020; Stuch and Alcamo, 2024). For instance, interventions aiming to increase smallholder farmers' incomes (a poverty alleviation target) by linking these farmers to export markets might make these farmers more vulnerable to unpredictability (as global markets are often volatile (Sharif and Irani, 2017)) while also subjecting them to undesirable trade-offs – for instance, creating a shift in consumption patterns that compromises nutrition and health - as in the case of quinoa (Conti et al., 2021a; Perez et al., 2011) (See Box 1.).

2.2. Path-dependencies (2)

Path-dependency refers to the historically established trajectory in which agri-food systems evolve (Conti et al., 2024b, 2021b) – a concept often linked to the idea of lock-in, used to describe system “blockages”that lead to the exclusion of competing views and practices (Conti et al., 2021b, p. 2). For interventions, path dependency and lock-ins create a difficulty in dislodging pre-established patters. For instance, in case of new technology adoption (a “technology lock-in”(Hammond Wagner et al., 2016)), as skills, knowledge, infrastructure and policies co-evolve to support the existent, rather than the alternative, technology. Path dependency could also manifest as tendency to “stick to what is known” in the intervention logic (Conti, 2024), e.g. the prioritisation of short-term over long-term goals, or the belief that export-markets are the most effective way to increase incomes (Glover et al., 2021b; IPES, 2016).

2.3. Context specificity (3)

Features of agri-food systems vary greatly across places. Interventions are thus faced with a variety of contexts that do not simply have different environmental features (e.g. different agro-ecological zones) (Ericksen, 2008; Fraser et al., 2005) but also exhibit specific economic and social dynamics, which shape interactions and patterns of practice (Glover et al., 2021a; Guenin et al., 2022) – for instance determining what is “acceptable” or “desirable” and influencing actors' preferences and behaviours (Bruce and Spinardi, 2018; Gonçalves et al., 2015).

2.4. Power relations (4)

Incumbent agri-food systems (large food processors, traders, retailers and big input agribusinessoften attempt to protect their interests or expand their power (Clapp, 2022; Williams et al., 2023). Through their actions, incumbents can shape the direction of change of agri-food systems to adhere to their interests (Anderson et al., 2023; Murphy et al., 2012). For instance, they can create obstacles for interventions that might adversely affect them – as in the case of chemical dealers during

Box 1
Promising interventions and unexpected trade-offs: the story of Quinoa

Quinoa was a subsistence crop for small-scale farmers in the Andes. In an attempt to raise farmers' incomes, it started being marketed as the “miracle grain” of the Andes. International sales soon soared. However, as quinoa popularity and demand increased globally (especially from consumers in the US, Canada, Australia and the UK) this generated several unanticipated consequences (Conti et al., 2021a; Perez et al., 2011):

i. Increased export demand increased quinoa prices, making it “more expensive than chicken” (Perez et al., 2011), and thus unaffordable for the traditional Andean consumers, who had to switch to cheaper, less nutritious alternatives (e.g. fast foods).
ii. Export demand altered farming practices, favouring mechanisation and prioritising quinoa over other crops, thus at once reducing diversification and creating sustainability issues (e.g. soil health, biodiversity).
iii. Increased demand for quinoa opened the market to other competitors (e.g. US), thus creating a threat to Andean farmers., who may struggle to compete with new producers.

the implementation of Integrated Pest Management via Farmer Field Schools in Indonesia (van de Fliert, 1993). They can also, as in the case of the UN Food System Summit label interventions that reduce agrochemical inputs (e.g. agroecology) as unviable at scale, in an attempt to preserve their profits (Anderson and Maughan, 2021; Canfield et al., 2021) Despite the importance of these power relations, more in-depth political economy analysis that can reveal power relations is rarely implemented in practice (Leeuwis and Wigboldus, 2018; van de Fliert, 1993).

2.5. Spatial (5) and temporal (6) scale mismatches

Further complicating intervention design, implementation and impact, are the multiple spatial and temporal scales that interlink in agri-food systems creating ambiguous boundaries (Halbe and Adamowski, 2019). On the one side, multiple spatial scales intertwine when addressing food-related challenges – with local, national and supranational dynamics continuously co-evolving (Hebinck et al., 2018; Marchetti et al., 2020). On the other side, multiple temporal scales make agri-food systems difficult to operate in – creating uncertainty regarding immediate versus delayed impacts (GFFN, 2023). Interventions in the agriculture and food sector have to face the interplay of behavioural, technological, institutional and social drivers that might change under different timespans and interplay differently across scale and geographies (Conti et al., 2021b; Woltering et al., 2019).

Several authors have suggested that an agri-food system perspective could help deal with some of these sources of complexity (Mausch et al., 2020; Thompson and Scoones, 2009). In contrast to food system research, where the focus has been on how systems can absorb perturbation and maintain their functions (Dekeyser et al., 2020; Thompson and Scoones, 2009), the agri-food system perspective embraces uncertainty and suggests that disturbances can represent critical opportunities for doing new things and open new ways of innovation and experimentation (Mausch et al., 2024; Thompson and Scoones, 2009). An agri-food system perspective would also encourage the recognition contexts are unique and inherently diverse (Pimbert et al., 2003; Thompson et al., 2007) and thus demands the development and implementation of context-specific solutions (Hambloch et al., 2022; Leach et al., 2010). Whereas much of today's policy and practice attempts to maintain the *status quo* or control change (Douthwaite and Hoffecker, 2017; Thompson and Scoones, 2009), the agri-food system perspective forefronts the value of being able to respond, cope with and shape change (Hertz et al., 2021; Thompson et al., 2007). Table 1 presents the sources of complexity and how mainstream approaches (and earlier framings of interventions) usually engage with them, based on the review of the literature conducted above. Then, it compares this "orthodox" way of dealing with complexity (Mayne et al., 2017) with the principles emerging from an agri-food system perspective as illustrated by (Hertz et al., 2021; Thompson et al., 2007; Thompson and Scoones, 2009).

In summary, understanding that "surprises" are inevitable within agri-food systems interventions alerts us to the reality that causes, effects, and results might turn out to be sharply different from what was initially predicted (Millstone et al., 2009). Adopting an agri-food system perspective that is more aware of complexity might encourage the adoption of a much more open and flexible approach that seems extremely valuable in an era of growing uncertainty (Hall and Dijkman, 2019). However, the way that this lens can inform development practice remains, to date, largely theoretical rather than practical (Forney and Dwiartama, 2022; Rivera-Ferre, 2012).

Table 1
Sources of complexity, mainstream approaches, and principles of a complexity-aware perspective in agri-food systems.

Sources of complexity in agri-food systems	How do mainstream interventions tackle this?	Principles of a complexity-aware agri-food system perspective
Unpredictability (even in trade-offs)	Pre-defined pathways of change that poorly accommodate unpredictability, no in-depth discussion of trade-offs.	Welcomes surprises and openly discusses trade-offs.
Path dependencies	Overlooked.	Shuns orthodoxies in "what works, and where" and encourages flexibility and learning
Context-specific dynamics	Frequent tendency to often do "more of the same, somewhere else".	Engages with context-specificity.
Power relations	Political-economy analysis preceding interventions rarely conducted.	Exposes patterns of power and explores potential impacts of power dynamics.
Spatial and temporal scale mismatches	Ambiguous boundaries between multiple scales of agri-food systems, project cycles and M&E demanding evidence of quick change.	Understands the multi-scale nature of agri-food systems contexts and embraces the lengthy nature of change.

3. Methods

3.1. Analytical approach

The paper uses a comparative analysis of case studies. The method is suitable for comparing and contrasting across contexts and, through an extensive degree of conceptual, analytical and synthesising work (Goodrick, 2017), finding patterns that can "trace across individuals, groups, sites, or states" (Bartlett and Vavrus, 2017, p. 11) – in this case, to reveal manifestations of complexity across different contexts and illustrate principles for tackling this in agri-food systems. The six case studies analysed in the paper are projects implemented by the CGIAR often in collaboration with local actors. Data for the case studies was collected as part of the CGIAR Research Program on Grain Legumes and Dryland Cereals (GLDC). The CGIAR has been working with agricultural and food system frameworks for decades (CGIAR, 2020; Greenland, 1997; Leeuwis et al., 2014; Pingali, 2001), and the case studies represented interventions aimed either at increasing smallholder farmers' incomes or addressing food and nutrition security, or both. These six case studies were specifically selected as they were all affected, in different ways, by some of the sources of complexity, which ultimately hampered the achievement of their objectives. As these cases are retrospective, rather than ongoing, their dynamics can be observed in a way that does not aim for simplistic causal explanation of success or failure, but rather, attempts to gain a more in depth understanding of how complexities emerged and how they were navigated.

The case studies are: aflatoxin control in groundnuts in Malawi (1), pigeonpea in Eastern and Southern Africa (ESA) (2), sorghum beer in Kenya (3), sweet sorghum for biofuel in India (4), precooked beans in Uganda and Kenya (5), Smart Foods in India and Eastern Africa (6). The purpose is not to evaluate or critique the interventions that form the case studies, which were not, after all, designed with an agri-food system perspective in mind. Rather, the purpose is to illustrate how complexity manifested within these interventions and to suggest general principles that could help future interventions tackle such complexity.

3.2. The case studies

The case studies are now briefly summarised below. A full description of each case study with supporting references is provided by Orr et al. (2022).

3.2.1. Case study 1: Aflatoxin control in groundnuts in Malawi

The intervention to control aflatoxin in Malawian groundnuts attempted to increase smallholders' incomes by re-capturing EU markets for groundnuts, once Malawi's main destination for exports. These legumes were once one of Malawi's main sources of foreign exchange.

However, in 1982, the European Union (EU) suddenly imposed a regulation on the mmaximum allowable limits of aflatoxin in foods. The Malawian groundnut sector was not able to meet these new quality standards as the aflatoxin contamination could occur at all stages of the value chain, making it a challenging issue to address. As a consequence, smallholder groundnut producers who produced the majority of the Malawian exports were excluded from EU groundnut markets. One of the CGIAR centres, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) wanted to ensure that farmers could again benefit from accessing these markets. In partnership with the National Smallholder Farmers' Association of Malawi (NASFAM), the "Fairtrade model" was developed between 2002 and 2008 and aimed to develop a quality assurance system. By monitoring levels of aflatoxin using cheap test kits, farmers could once again sell standard-compliant groundnuts into EU markets. Also, farmer groups certified for Fair Trade could obtain a premium price for their groundnuts. In 2003, NASFAM partnered with TWIN Trading, a London-based Fairtrade organisation, to promote sales of Malawian groundnuts in the UK and, in 2004, they obtained Fairtrade International Certification for the Mchinji Area Smallholder Farmers Association (MASFA). Between 2007 and 2011 TWIN provided a market for over 4000 MASFA farmers and, based on consumers' willingness to pay a premium for 'ethical' products, generating an income of $527,000. However, of the 42 associations composing NASFAM, only MASFA was able to obtain the Fairtrade certification, meaning that the the Fairtrade model worked as a pilot, but could not be replicated at scale in Malawi.

3.2.2. Case study 2: pigeonpea in ESA

The projects on pigeonpea in ESA aimed to produce varieties of pigeonpea and increase farmers income by taking advantage of the high Indian demand for pigeonpea.

Pigeonpea is an integral part of many people's diet in India, and demand is often too high to be met by domestic markets. ESA is a major producer of pigeonpea (Orr et al., 2022). ICRISAT capitalised on this opportunity by setting up a breeding program that produced improved varieties to supply these export markets at the right time. Africa's harvest of pigeonpea is earlier than in India, allowing exports from ESA to benefit from peak prices between July – December before the Indian crop reaches the market. Varieties thus had to a) be suitable for cultivation in ESA, b) have market traits favoured by Indian consumers, and c) reach India when prices were high. The program, which started in 1991, can be considered as an early example of market-led breeding inspired by the idea of market-led development. The breeding program was in the right place at the right time. In 2000, imports of pigeonpea to India were 44,000 t, and by 2015, imports had reached 450,000 t, with half coming from ESA. However, in 2017, India's sudden imposition of an import quota for pulses caused an abrupt stop to these exports.

3.2.3. Case study 3: Sorghum beer in Kenya

Sorghum beer in Kenya aimed at raising smallholder farmers' incomes by introducing a novel beverage - Senator Keg beer – partly subsidised by the government as an alternative to illicit and harmful brews in the country. Producing this beer offered farmers a bigger market and higher prices for their sorghum production. 'Senator Keg' was produced and marketed in Kenya by East African Breweries Limited (EABL). The beer emerged as a response to two opportunities. One was an emerging market for clear sorghum beer, and the advantages such a market presented for smallholders in semi-arid areas who traditionally grew sorghum. The second was a public health scandal of deaths from the consumption of illicit brews, which challenged government legitimacy (Hesse, 2015). Illicit brews were consumed by low-income consumers, who could not afford costlier but "safer" beers. Senator Keg was targeted at poorer consumers and offered farmers a substantially higher farmgate price for their sorghum. However, to compete on price with illicit brews required a government subsidy. The Ministry of Finance agreed to waive the excise duty that it normally charged on beer. Without this subsidy, the price of sorghum beer would have been higher than most illicit brews, and low-income consumers would not have been willing to switch. This tax break was critical to the success of sorghum beer. In 2013, however, the subsidy was suddenly removed, Senator Keg's price shot up, and its purchases fell by 75%.

3.2.4. Case study 4: sweet sorghum for biofuel in India

This case study aimed at introducing sweet sorghum as a new source of biofuel and raising the incomes of smallholders producing the crop while tapping into the potential of the biofuel market in the subcontinent. Demand for biofuels is particularly high in India due to the country's high crude-oil imports.

In India, most biofuels are made by blending petrol and ethanol produced from molasses, a by-product of sugarcane. However, sweet sorghums have a higher fermentable sugar content and can be used as biofuel. Sweet Sorghum also has a four times lower water requirement and can be grown in semi-arid areas which presented a significant opportunity to raise smallholder farmers' incomes in these less favourable environments. The waste product from sweet sorghum's processing into a biofuel can further be used as cattle feed. Leveraging its long history of genetic improvement of sorghum, ICRISAT switched some of its research programs to focus on sweet sorghum for biofuels. In 2007, it launched a BioPower Initiative in partnership with the Indian National Agricultural Research Systems (NARS). BioPower aimed at designing and testing a prototype value chain for sweet sorghum in the main sorghum-growing regions of India: Maharashtra, Uttar Pradesh, and Karnataka. The initiative trained farmers on how to manage the production of the new sweet sorghum varieties and was able to attract private investors, thus demonstrating the technical viability of the model of Sweet Sorghum for biofuels. However, sugarcane benefited not only from subsidies that reduce the cost of production but also from a Minimum Support Price. Without similar government support sweet sorghum could not compete in the market. A similar subsidy that would have put sweet sorghum into a competitive position and could have been justified by environmental benefits or by the income benefits to smallholder farmers was never implemented.

3.2.5. Case study 5: precooked beans in Uganda and Kenya

The innovation of precooked beans in Uganda and Kenya tried to build a new value chain for iron-fortified, precooked beans to both improve nutrition and raise smallholder incomes.

Common bean is a staple food crop in Eastern Africa. Consumers usually buy dry, unprocessed beans, which require 2–3 hours of cooking time. This is a significant cost in terms of fuel and women's time. The project thus focused on "precooked beans", which would be produced mainly by smallholder farmers. Precooked beans could be cooked in 15 minutes, saving consumers both time and money. Being high in iron, beans could also tackle a widespread nutritional deficiency. For this, high-iron bean (HIB) varieties needed to be available (this was possible only because biofortification had long been a priority for bean breeding programs). A supply chain had to be built ex novo to accommodate the novel product. Newly introduced HIB varieties required developing a seed system to supply farmers with these seeds, while consumers' demand had to be created. Even if it had to be anticipated that these tasks could not be achieved in a short time span, the project was still criticised for its "slow growth".

3.2.6. Case study 6: smart foods in India and Eastern Africa

The Smart Foods initiative in India and Eastern Africa undertook the challenge of changing consumption patterns in India and ESA using small-scale pilots to promote healthy diets, encouraging the consumption of millet and sorghum.

'Smart Food' was the brand name ICRISAT gave to consumer products made from its mandate crops sorghum and millet. Launched in 2013, the initiative aimed at shifting consumption patterns in India and ESA from the three staple foods (rice, maize, and wheat) to millets and

sorghum, which had a higher nutritional content. Smart Food products were targeted primarily at urban, middle-class consumers with high purchasing power but at risk from lifestyle diseases such as obesity and diabetes. The Smart Food problem was framed as one of consumer demand – or the need to ensure consumers perceive and consequently buy and consume these "healthy foods". Consumers were made aware of the environmental benefits of Smart Foods ('good for the planet, good for the farmer' (Finnis, 2012)) and the importance of these foods for improving culinary diversity. The initiative attempted this through a TV show (where contestants produced dishes using Smart Food ingredients that were judged by professional chefs) and by publishing books with novel recipes for cooking millets and sorghum. Both mainly targeted middle-class women, projecting a 'modern' image for millets. The initiative also targeted rural households. To reduce malnutrition, the Smart Food initiative targeted rural women used a 'home economics' model, developing partnerships with local governments and conducting workshops and participatory cooking classes. If the Smart Foods initiative created awareness and interest, changing eating habits is difficult and lengthy. The Smart Food initiative demonstrated the *potential* benefits of changing consumer behaviour, but any changes at scale in behaviour and demand for millets will be long-term and measured over generations.

4. Results: an analysis of encounters with complexity

This section discusses the sources of complexity manifested within the different case studies, highlights its consequences for the interventions, and discusses how an agri-food systems perspective could have helped tackle them (see Fig. 1 for a succinct visualisation).

4.1. Unpredictability and path-dependencies in Agri-food system interventions: Aflatoxin control for groundnuts in Malawi and pigeon pea in ESA

Unpredictability and path-dependencies emerged as two sources of complexity in two case studies.

The intervention for aflatoxin control for groundnuts in Malawi intervention was set up to counter the unpredictable disturbance of aflatoxin regulation from the EU and regain entry into this market. This reflects the tendency of interventions to try and counter change by trying to revert to a "known" state (Thompson and Scoones, 2009). It further highlights path dependency as it follows a long-back established approach to gain (or re-gain) access to lucrative export markets as the best way forward to raise smallholder incomes (Biénabe et al., 2016; IPES, 2016; Kay, 2015; Koech et al., 2016; Toenniessen et al., 2008). For instance, an ICRISAT report states: "connections to markets are the most effective means for escaping poverty" (ICRISAT, 2010, p. 23). Market linkages are generally considered the quickest and easiest way to alleviate poverty (Anitha et al., 2019; Calo et al., 2005; Zeller et al., 1998).

Instead of adopting the "export framing", the loss of export markets for the Malawian groundnuts could have opened the way to technical innovation around value addition. Rather than focusing on unprocessed nuts for export, the attention could have shifted to unleveraged opportunities in terms of groundnut oil, which is aflatoxin-free (contamination can be easily filtered out through a simple filtration process) and in high demand in African and international markets. While, on the one side, this would have demanded a quick change in priorities for plant breeding to respond to new circumstances, this might have solved the aflatoxin-control issue at a stoke (Orr et al., 2022). On the other side, by framing control of aflatoxin as an 'export issue' and not a broader issue of public health, this strategy has effectively re-directed toxins into domestic and regional markets (Orr et al., 2022). Since aflatoxin regulations in these markets are not enforced, producers or exporters had no incentive to comply with them. By reframing the issue as a general public health concern rather than blaming outside forces for the lost markets, the public perception and incentives to control aflatoxin in groundnuts could have been anchored across the population.

Pigeon pea in ESA illustrates similar processes at play. It was very successful for over 15 years but was later hampered by the unanticipated imposition of an import quota for pulses in India. Similar to the case of groundnut exports from Malawi, this relatively unpredictable event was a fundamental disruption of the intervention logic, and the sector could neither prepare for nor respond to this relatively unpredictable event. The intervention remained anchored to the well-established conviction that export markets are the quickest way to alleviate poverty (ICRISAT, 2010; Toenniessen et al., 2008). Instead, one could have responded to

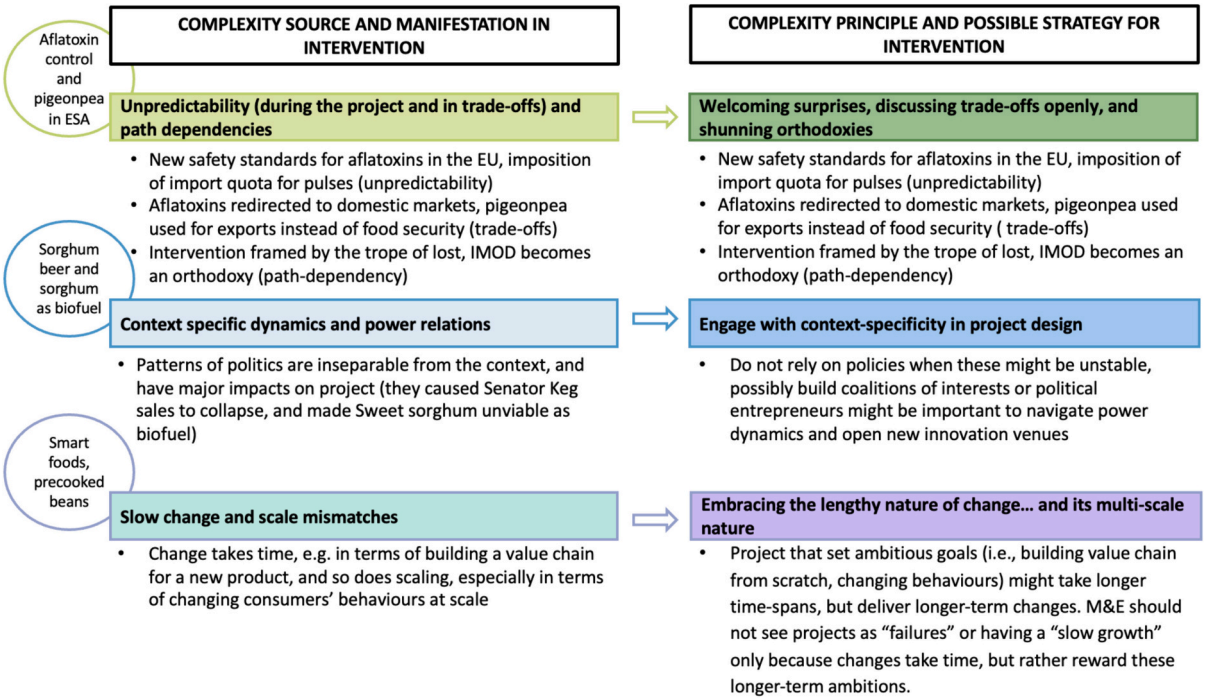

Fig. 1. Complexity sources and possible complexity-aware strategies in selected interventions.

the import quota by focusing on pigeonpea for domestic consumption – thus contributing to household food security and nutrition – rather than on exports. Besides, the case study, alongside similar projects, led to the institutionalisation of its approach, under the name of Inclusive Market-Oriented Development (IMOD) (Srinivas Rao et al., 2014), highlighting the mainstream tendency of many development interventions to "find out what works and do more of the same somewhere else" (Wigboldus et al., 2016). Being more aware of the importance of avoiding path-dependency might have helped prevent the later application of the IMOD approach indiscriminately - even when inappropriate (Orr and Muange, 2022). By welcoming surprises, openly discussing trade-offs, and shunning orthodoxies, these interventions might have leveraged new opportunities and avoided certain drawbacks.

4.2. Context-specific dynamics and power relations in Agri-food system interventions: sweet sorghum as biofuel in India and sorghum beer in Kenya

Both sweet sorghum as biofuel in India (case study 3) and sorghum beer in Kenya (case study 4) successfully identified promising market opportunities. And yet, these interventions were challenged - in different ways - by the concealed context-specific and highly political dynamics in these two regions.

Sorghum beer in Kenya tapped into the potential of East African beer markets, by making the price of the beer competitive with illicit brews and, at once, raising the incomes of farmers producing sorghum and increasing consumption of a local beer. This competitive price was only possible because of a government subsidy. Similarly, despite the potential of the sweet sorghum as biofuel, an innovation to benefit farmers and the environment, the government did not adjust economic incentives for the innovation to be adopted at scale.

Why was the subsidy in Kenya suddenly removed? In the same manner, why did the government of India not subsidise sweet sorghum as it did with sugarcane when the innovation could demonstrate its potential benefits? The answer to both questions points at concealed elements of complexity: the place-specific and political nature of the Kenyan and Indian contexts Kenya, the unforeseen removal of the indirect subsidy could be attributed to political dynamics (Orr, 2018). The introduction of the subsidy had been decided under the government of the democratic party that came into office in 2002 However, when the opposition party won the election in 2012, the new government reassessed their priorities and the sorghum beer subsidy was removed. The new government was under considerable pressure to reduce the high fiscal deficit, which made it critical to raise tax revenue. This policy decision left a legacy of uncertainty for the totality of the value chain: "the success of sorghum beer in Kenya rested on fragile foundations that could crumble overnight if the government changed its mind" (Orr, 2018, p. 49). Even though the subsidy that was dropped in 2013 was re-established in 2015, frequent changes in tax policies over the years kept hanging as a "Damocles' sword" on the intervention, representing an uncertain threat that could unexpectedly strike at any moment.

The failure of sweet sorghum as biofuel in India could also be attributed to concealed political realities operating in the regions where sweet sorghum is grown. The states that presented suitable agroecological zones for the cultivation of sweet sorghum (Karnataka and Maharashtra) were the same states that have historically been strongholds of the sugar industry (Jitendra, 2019; Orr et al., 2022). The absence of support can be attributed to the sugar lobby – which is traditionally strong not only in India but globally. The lobby wants to preserve its interests and, through its close ties with political players, opposes subsidies to sweet sorghum that would endanger their revenue from sugarcane (Orr et al., 2022; Saravanan et al., 2018). More carefully considering these dynamics before the set-up of the interventions might have helped find alternative or complementary strategies to address these contextual political issues. For Senator Keg, this might have involved novel business models that could make the beer competitive even without the tax break (Orr et al., 2014) – and accepting the lack of certainty inherent to policies or subsidies. A stronger national farmers' organisation could also have been created as a way to prompt a coalition of stakeholders and avoid the reversal of the policy (Orr, 2018). Similarly, recognising that sweet sorghum needed to be supported by a strong political coalition that could counter the influence of the sugar lobby might have helped the innovation gain essential political support (Pradhan and Ruysenaar, 2014; Raju et al., 2001; Saravanan et al., 2018).

These cases highlight the importance of recognising and acknowledging these issues as it will otherwise be impossible to solve them. The agri-food systems lens here sheds light on the importance of engaging with context-specificity and exposing concealed power relations.

4.3. Slow change and multiscale issues in Agri-food system interventions: smart foods in India and eastern Africa and precooked beans in Uganda and Kenya

Interventions to promote pre-cooked beans in Uganda and Kenya (case study 5) and the Smart Foods in India (case study 6) embarked on the ambitious task of changing consumer behaviours by developing novel value chains or creating awareness of new healthier foods. However, both witnessed slow changes and encountered scale mismatch issues as elements of complexity.

Precooked beans were a promising innovation. The project set the bold goal of building a value chain for the product. This involved managing multiple and interconnected parts of the bean value chain and coordinating ten steps: i) screening and identifying suitable varieties; ii) multiplying seed using farmer groups; iii) producing grain through farmer groups; iv) aggregating grain and delivering to processors; v) establishing processing plants; vi) ensuring production and sale are profitable; vii) winning product approval from the Bureau of Standards; viii) identifying consumers willing to buy the product; ix) raising consumer awareness of nutrition benefits; x) ensuring a continuous supply to meet consumer demand. Tackling all these steps synchronously was challenging for the intervention and required time and effort for coordinating different actors and activities. Furthermore, the ten steps were dispersed over time and space making coordination and linkages more complex than interventions that focused on a single component. Yet, the project was frequently criticised for its slow progress (Aseete et al., 2018; CASA, 2020) – instead of praised for engaging in the challenging task of building a value chain "from scratch". Building a value chain is a long-term investment (and a critical objective for many development interventions (Staritz, 2012)), and a 2.5 years project time-span is inadequate to ensure harmonisation between a wide range of stakeholders and all the "moving parts" parts of the value chain.

The lengthy nature of change also hampered the Smart Foods initiative. While the initiative could demonstrate the *potential* benefits of consuming these foods, it could not change consumption patterns at scale. While changes in consumption are relatively easier to witness in pilot projects (Obih and Baiyegunhi, 2017), ensuring that they are widespread requires much more concerted efforts – for instance, changing consumption patterns in India or ESA would require interconnected actions on several fronts, such as legislation, education, restrictions on advertising, and a public health campaign (Epstein et al., 2012; Powell et al., 2013). The expectation that these changes could be achieved quickly is unrealistic. Instead, it is increasingly recognised that interventions aiming for shifts in production or consumption (or the value chain itself) cannot be achieved swiftly (Govaerts et al., 2021; Leeuwis et al., 2017). And yet, many M&E frameworks – and the donors' expectations underpinning them (IPES, 2016) – still look for proof of quick impacts (IPES, 2016; Leeuwis et al., 2018), thus underestimating the complexity of achieving deeper changes in agri-food systems (Govaerts et al., 2021). Embracing the lengthy nature of change would require a major shift in donors' perceptions (and evaluation) of "success" from a shorter to a much longer term perspective (Glover et al., 2021b;

Schut et al., 2020). This shift in vision and priorities could help better embed more long-term objectives in intervention logic and provide stronger backing and justification for interventions having more ambitious goals (e.g. building a value chain, changing behaviours) (Glover et al., 2021b; Govaerts et al., 2021; IPES, 2016).

5. Discussion: embracing complexity

The case studies show that interventions rarely go as planned. The agri-food sector is tasked with delivering a wide range of benefits – generating incomes and employment, providing safe and nutritious foods, preserving natural resources and biodiversity – and is linked to the functioning of other sectors (e.g. mobility and transport) (Christiaensen et al., 2011; Loizou et al., 2019). Therefore, the multi-scale (across space and time) and multi-fold nature of impacts that agri-food systems can deliver make it an extremely challenging space to navigate and enact change. This complexity could be an obstacle, but also an opportunity towards "new ways of doing things" (Thompson and Scoones, 2009), if engaged in the right manner.

The case studies aimed to show how intervention designs (and inherent M&E) could better navigate this complexity[1] by following agri-food systems principles (summarised in Fig. 2).

The importance of welcoming surprises emerges in the aflatoxin control for groundnuts in Malawi and pigeonpea in ESA. Moving away from attempts to "combat" change and re-establish a known state, a more flexible approach that welcomes disturbances as new ways of doing things could have opened the way for opportunities in more lucrative domestic markets. This is in line with more recent literature, which highlights that linear conceptualisations (or theories) of change are no longer appropriate (van Tulder and Keen, 2018; Wigboldus et al., 2016). Perturbations and unforeseeable changes of circumstances make "an *output-orientation* becomes untenable" (Kok et al., 2023) in an era of global change and transformation (Hall and Dijkman, 2019). Instead, it is more useful to embrace a flexible approach that can enable interventions to respond to (rather than control) the dynamic and evolving context. At the same time, these two case studies draw attention to the need to shun orthodoxies in the way interventions are designed and implemented (Conti, 2024). For example, this would have helped

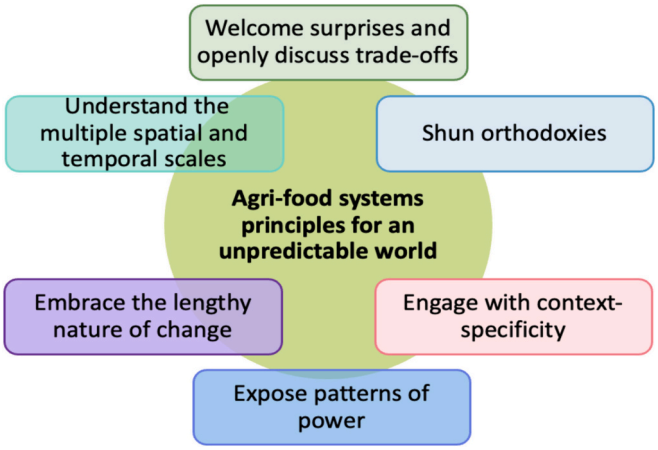

Fig. 2. Principles for navigating complexity in agri-food systems interventions.

question the export-oriented logic in which both aflatoxin control for groundnuts in Malawi and pigeonpea in ESA were rooted (Aflasafe, 2019; Kaoneka et al., 2016). Instead of narrowing the focus on only one solution (i.e. access export markets), a more open and critical approach that questions underlying assumptions that might not, in truth, be always relevant or beneficial for interventions (Borrella et al., 2015; Liverpool-Tasie et al., 2020; Mausch et al., 2020).

A broader agri-food system perspective that takes cognisance of complexity could also contribute to identifying and clearly discussing trade-offs. The focus on export markets for groundnuts generated a trade-offs not only in terms of exploring alternative opportunities (e.g. groundnut oil), but also, while increasing incomes for some smallholders, re-directing aflatoxins into domestic markets. In the case of pigeon pea, focus on export markets ruled out the value of the crop for domestic food security. Both cases not only hint at trade-offs, but also at an overarching tendency in interventions to "follow what is known", i.e. for instance, the tendency to rely on export markets for poverty alleviation, as opposed to a more systemic vision of what works where (e.g. groundnut oil for domestic consumption) and what objectives should be prioritised (e.g. incomes vs nutrition). This tendency is well acknowledged in the literature (Hertz et al., 2021; IPES, 2016; Ng'endo and Connor, 2022). Therefore, not only a much more open and honest discussion on trade-offs might be needed, but also, a broader reflection on path dependency within development and research narratives that currently shape how interventions are envisioned (Conti et al., 2021b), often ruling out broader, and more diverse, ranges of options (Mausch et al., 2020).

A key feature of an agri-food system perspective is its recognition that each place has its own unique dynamics, which inevitably plays out in and beyond the intervention. This is particularly so in terms of power relations playing out in different agri-food system contexts (Clapp and Ruder, 2020; Kalvelage et al., 2023; Kok et al., 2021). For example, the cases of sweet sorghum as biofuel in India and sorghum beer in Kenya illustrated how embedded political patterns shaped the intervention implementation and its outcomes. It could be argued that changing such patterns is an extremely ambitious task, that goes beyond single interventions and requires much more systemic action (Béné, 2022; Fanzo et al., 2021). However, it could also be argued that pre-emptively studying and understanding the political and other dynamics of different contexts is a critical first step in intervention design (Hambloch et al., 2022). Exploring how these dynamics might shape and direct actors' behaviours and the way this affects intervention outcomes provides a way to identify mitigation strategies (Anderson and Leach, 2019). For example, this includes strategies that alter contextual bottlenecks, such as by building stronger networks or leveraging the influence of policy entrepreneurs or, alternatively, strategies that circumvent possible bottlenecks, such as ensuring interventions are not dependent on fickle policies.

Finally, the case studies' experiences confirm that agri-food system change has both spatial and temporal scales, the latter of which is usually over looked (Conti et al., 2021b). This means understanding that change does not always happen synchronously between spatial scales, nor adheres to fixed and often short-term deadlines. Interventions might take longer than planned, or even be repeated at different temporal scales to enhance their impacts (Beck et al., 2021; Glover et al., 2021b; Sarabia et al., 2021). For example, in the Smart Food intervention, changes at the project scale could be demonstrated relatively quickly, but the broader desired changes (i.e. a shift in consumption patterns to include millets and sorghum) will require much more concerted, or even more widely replicated action, to happen at broader geographical but also temporal scales. Furthermore, changes in the agri-food systems landscape would need to be harmonised with other changes at the broader level, such as, for instance, policies that subsidise these crops to be consumed by the poor (Thow et al., 2014), or multiple behavioural change interventions that can over time alter purchasing and eating habits (Andreyeva et al., 2022; Taufik et al., 2019). As the case of pre-

[1] It is, however, important to note that elements of complexity can manifest differently in different contexts, either singularly or together, combine in unexpected ways and with unexpected outcomes. Thus, an agri-food systems approach should not be adopted as an inflexible or prescriptive manner but instead, should always be adapted and revisited as needed.

cooked been demonstrated, building a value chain for a new product takes considerable periods of time as it requires innovation to ensure that multiple value chain components (and inherent actors) can work together. Many projects and M&E frameworks have short time-spans, underpinned by donors' own priorities and preoccupation in terms of achieving "success" without deviating from the established intervention's course (Govaerts et al., 2021). Instead, the agri-food system perspective invites a more realistic and accepting vision. This vision acknowledges the possible limitations in scale beyond the pilot interventions, or the longer time-spans required for interventions to explore and implement new pathways of change at multiple scales (Jagustović et al., 2019; Sartas et al., 2020; Woltering and Boa-Alvardo, 2021).

As a whole, these six principles highlight the value of a novel way of approaching interventions in agri-food systems that is not governed by generally accepted assumptions (Niewolny, 2022). Rather, it is open to reflexive and critical (re-)evaluation that prompts continuous experimentation and learning (Caniglia et al., 2021; Schlüter et al., 2022) to navigate through complexity (and re-setting the course when needed). In the case studies, we would argue that a lack of reflexive evaluation and mid-course corrections did not allow them to respond to changes in circumstances.

The implication here is that intervention should not attempt to control or shy away from complexity (Thompson and Scoones, 2009). Nor should they adhere to what is known to work as the only principle (Folke, 2006; Manyise and Dentoni, 2021). Pre-defined pathways of change that respond to "established notions of accountability" might no longer be relevant in 21st century food systems (Hertz et al., 2021). Instead, the principles that our case studies seem to confirm, highlight the importance of being open to unpredictable developments, and seizing them as opportunities to venture into different (and possibly more suitable) pathways of change (Thompson and Scoones, 2009). Interventions might need to be iteratively (re)defined with multiple stakeholders, including donors, who might need to be convinced of the value of a more flexible and open approach to change, which might lead to different, but possibly more context and time relevant outcomes (Hertz et al., 2021; Stirling, 2014). Involving a broader set of stakeholders in much more participatory and deliberative design and decision-making processes around interventions (e.g. through participatory approaches, or group modelling for understanding system dynamics (Guenin et al., 2022; Rich et al., 2018)) could be critical for practically applying the principles illustrated in this paper. This is why transdisciplinarity is increasingly considered as an essential feature of food system research (Marshall et al., 2018; van Bers et al., 2019). It has been argued that could help provide deeper contextual (political, environmental and other) knowledge, possibly unconventional solutions to deal with uncertainty, or providing deeper insights in the ambiguous evaluation of harms, benefits and trade-offs of agri-food system interventions (Kok et al., 2021; Stirling, 2010).

6. Conclusions

The paper aimed to better understand complexity, its manifestations, and possible ways to respond to it within agricultural development interventions. The six case studies, revisited through an agri-food system perspective, show how complexity plays out in practice. The discussion uses the agri-food system perspective to distil six principles to help interventions engage with this complexity. The authors, however, remain aware that the elements of complexity described in the paper can manifest differently in different contexts, and many more implications of such elements could be investigated. For instance, the emergence of impacts or trade-offs at larger scales or in other geographies was not covered in our analysis, and would require further study. Thus, an agri-food systems approach should not be adopted as an inflexible or prescriptive manner but instead, should always be adapted and revisited as needed. This is why it would be important to further test and refine the principles in the context of on-going initiatives. They could be particularly relevant in light of the agri-food system transformation agenda, as this is an agenda deeply involved in complex system dynamics and change processes. As this paper reveals, many of the concepts and ideas about complexity are already available and there is ample past project experiences to mine and learn from. The task of agri-food system transformation is urgent and there is no need to reinvent the wheel. The key task going forward is to embrace complexity in all of societies endeavours to create a better world and stop pretending complexity does not exist.

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CRediT authorship contribution statement

Costanza Conti: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Andrew Hall:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Alastair Orr:** Methodology. **Caroline Hambloch:** Writing – review & editing, Conceptualization. **Kai Mausch:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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